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Distal Forces Coincident to Unilateral Headgear Therapy

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DISTAL FORCES COINCIDENT
to
UNILATERAL HEADGEAR THERAPY

by

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The most profound gratitude I can express goes to my parents, for offering the greatest support and encouragement through my first thirty-two years of life and making me what I am.

VITA

Michael L. Wasuita was born on May 10, 1947 in Ogden, Utah, the son of John and June Wasuita. He was the second born in a family of six children, having one younger brother and four sisters.

He graduated from Ben Lomond High School in 1965 and began attendance at Weber State College in Ogden, Utah. After one year at Weber State, he interrupted his studies for two years to serve on a mission for the Church of Jesus Christ of Latter Day Saints in Germany. In the fall of 1968, he returned from Germany to finish his studies at Weber State where a Bachelor of Science Degree was received in 1971. In the following fall, he matriculated at the University of Louisville School of Dentistry. In June of 1973, he married Denise Tenney. A degree of Doctor of Dental Medicine was received in May 1975 and the following June he began a two year commission in the United States Navy Dental Corps, serving at the Submarine Base in Groton, Connecticut. In July 1977, he enrolled at the Graduate School of Orthodontics, and in postgraduate program in oral biology at Loyola University School of Dentistry in Chicago.

He has two children Clinton John who was born June 15, 1975 in Ogden, Utah and a daughter Tobie Ann who was born May 20, 1977 in Groton Connecticut.

DEDICATION

to my wife Denise

For her love, devotion, and patience

and to our children

Clint and Tobie

TABLE OF CONTENTS

INTRODUCTION

Asymmetrical malocclusion **occur** in orthodontics. This may be the result of tooth extractions or an abberant eruption sequence or perhaps a skeletal asymmetry.

Orthodontists are often required to move one maxillary molar an entire buccal segment a distance greater on one side than the other. This involves the application of eccentric forces to one side without disturbing a more correct relationship on the contralateral side, particularly when the mandibular arch can not be used for anchorage support.

The paramount problem, then, is not to obtain desirable movement of teeth, but to prevent undesirable movement in the more properly aligned segments of the arch.

It is felt by some orthodontists that, when using the facebow a longer outerbow arm should be employed on the side where greater distal movement is desired. In addition, some orthodontists feel that when this longer arm-shorter arm relationship is integrated with human biology, the clinical results are less than appreciable. It is further thought that the longer bow arm should be adjusted so as to compensate for undesirable lateral forces that may be introduced.

The questions that must be asked are:

1. What is the optimum difference in outerbow lengths that will produce the most efficient unilateral force?
2. What length should the shorter arm be?

3. What are the lateral forces that are introduced into the system?

The purpose of the study was an attempt to quantitatively evaluate distal and lateral forces when using the unilateral (eccentric) facebow. It was felt that determining the optimum outerbow length difference would be of value so that clinicians could more confidently apply unilateral headgear therapy.

REVIEW OF LITERATURE

Extraoral force is one of the oldest techniques used in orthodontics. Some of the old text books showed all varieties of headgear which were used in the early 1800's.[1] Kingdley, Case Angle[1], and many others used the headgear to exert pressure against malposed teeth. They were crude, cumbersome, and no doubt cooperation of the patient was difficult to obtain.[1]

At the turn of the century, Dr. Baker[1] introduced intermaxillary force. Many men found that there were limitations to this philosophy and supported their mechanics with extraoral support. Thus extraoral forces have been an integral part of orthodontics for a long time.[1]

The advantages of the extraoral appliance may be listed as follows:

1. It can be inserted by the patient.
2. It can be used either in the maxilla or mandible.
3. In some cases no lower appliance is needed.
4. It can be used to reinforce anchorage.
5. It can be used to distalize teeth in the maxilla.
6. It can be adjusted for unilateral force.

For unilateral adjustment of the facebow, the outerbow arm should be longer on the side one desires to create a greater distal force.[1-8]

Proper integration of extraoral traction into the orthodontic treatment is of utmost importance.

Since extraoral force can have an effect upon the facial skeleton, this has allowed us to accomplish objectives previously unobtainable. However, its uncontrolled use may result in undesirable treatment changes.[9-11]

The clinical use of bilateral forces is prevalent and an analysis of the distribution of such a system is useful. Haack and Weinstein,[2] in their research, noted that:

1. The difference in arm lengths of the facebow need not be great (data was not supplied). They must be sufficient only to alter the geometry into asymmetry and skew the force to one side.
2. The arms of the facebow should clear the cheeks so as not to introduce more undesirable lateral forces.
3. Small lateral forces on the molars are always developed by a unilateral design.

It is believed that these lateral forces can be manipulated by springing the outerbow arms inward or outward. This could cause all lateral reaction on one side or the other depending on which arm was bent.[2-5]

It must be emphasized that a true comprehension of biological response to force reaction could not be achieved without first gaining an accurate knowledge of the force action involved.

Though physiological tooth movement is governed by biological laws, it is initiated and maintained by force. In applying this principle, biomechanics and biophysics have been taken out of the ranks of empiricism and placed in it's righful company amongst the true sciences.[3]

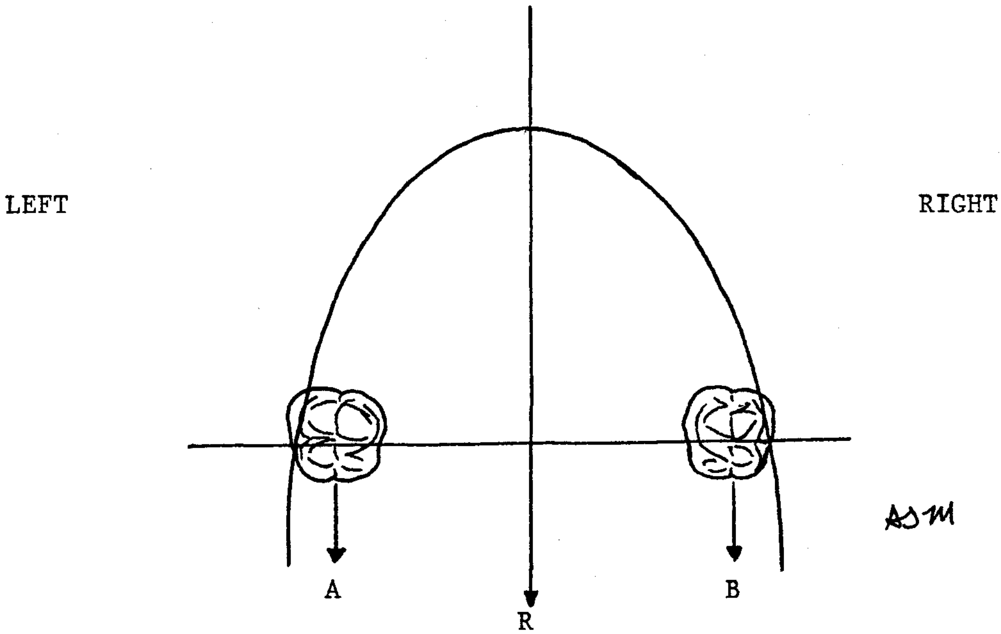
Armstrong [12] feels that, "Control of the mechanical variables dramatically increases the efficiency and effectiveness of extraoral force in the treatment of malocclusion, and it is apparent that there is an optimum direction for the application of extraoral force in each case for effective and efficient treatment."

Greenspan[13] brought out the need to quantitatively evaluate distal and lateral forces. He states that, "Exceedingly long or short arms of the facebow direct the force farther away from the tooth center of rotation. Therefore, it produces excessive tipping in a bilaterally symmetrical cervical traction therapy."

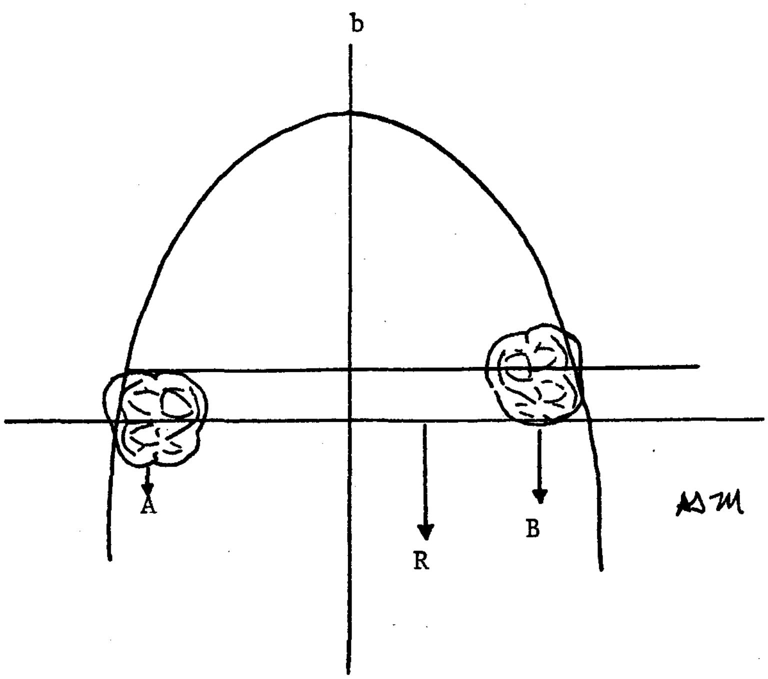
There are possible interferences that may confuse unilateral headgear therapy. Some orthodontists feel that the friction of the neck strap may or may not permit unilateral force to the desired side. Most feel that the friction is negligible after the neck strap has been worn a few times.[2,4] It is also felt that excessive flexibility of the facebow may interfere with unilateral action.[5]

An evaluation via a schematic representation of bilateral and unilateral therapy would be valuable at this time (figure 1).

If forces A and B were equal, the resultant force R could replace A and B together. The force would be in the midline and in the same direction, with a magnitude equal to the combined force of A and B (figure 1a).



a. THE RESULTANT FORCE R IS EQUAL TO THE COMBINED FORCES OF A AND B.



b. TO EXERT A GREATER FORCE ON B, THE RESULTANT FORCE R MUST BE CLOSER TO THAT SIDE.

Figure 1

However, if force B is to be greater than force A, then the resultant force R will be closer to B (probably not in a straight distal direction) (figure 1b).

Assuming that the patient is relatively symmetrical with respect to the midsagittal plane, can the distribution of forces be such as to include unequal posterior forces on the right and left molars and still satisfy the conditions of equilibrium?

The conditions of one plane equilibrium are:

1. The sum of the forces in the vertical direction are zero.
2. The sum of the forces in the horizontal direction are zero.
3. The sum of moments about any point equals zero.

Now, if a rigid helmet were securely fastened to the head or neck, unequal forces could be applied to A and B, but even this procedure would demand the use of clamps to secure the apparatus. The question now presents itself, how can the conventional elastic strap be used? The elastic strap, by its very nature, applies forces that are of equal magnitude right and left.[2]

A unilateral facebow should now be considered (figure 2). This is cervical traction in which one arm of the facebow is longer than the other and the connection between it and the arch is solid.

On figure 2, the right molar is forward a distance (d) with respect to the left molar. The forces Fl and Fr applied by the elastic strap are equal in magnatude but because of the unequal arm lengths of the facebow, the direction of these forces is not symmetrical in relation to

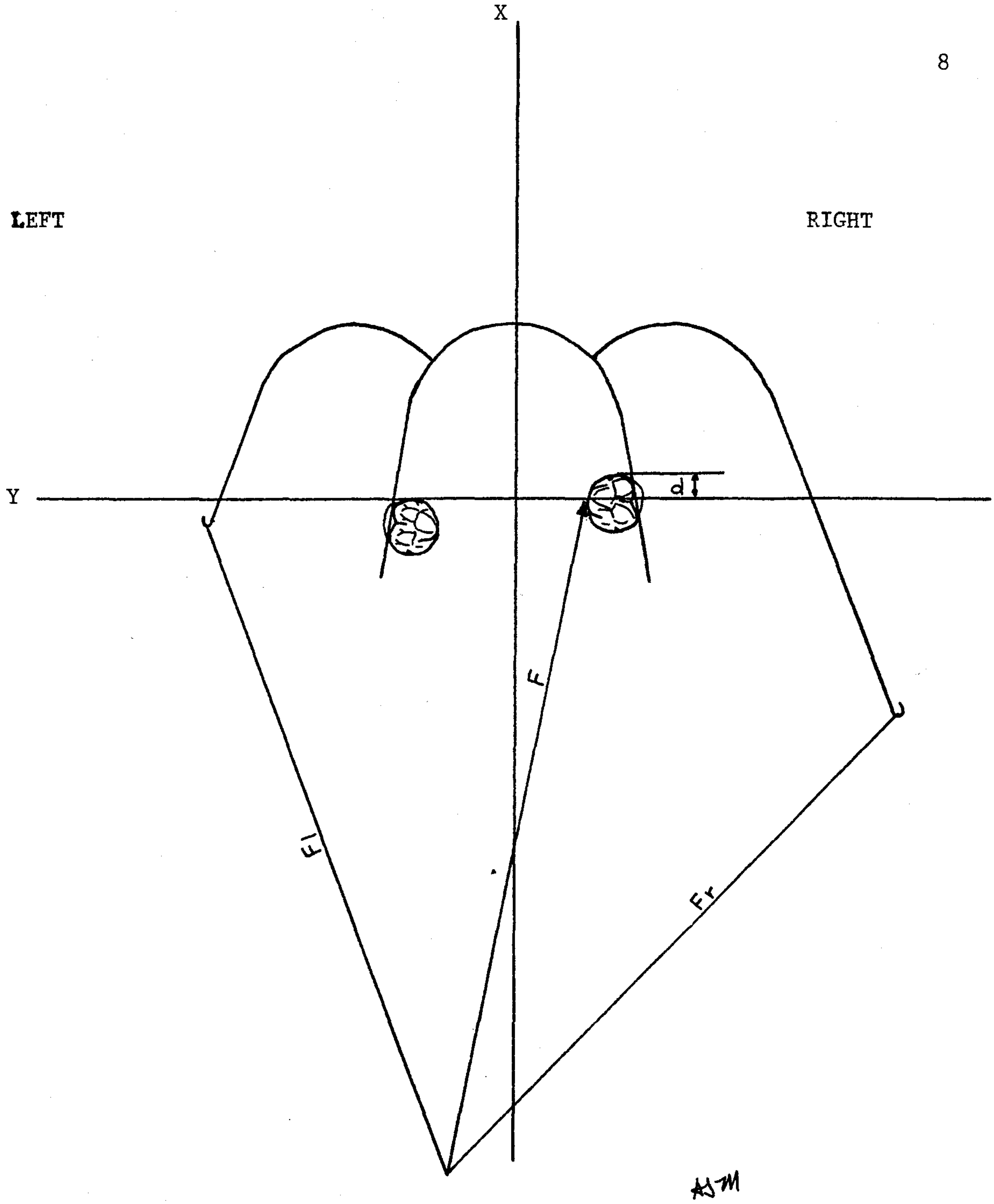


Figure 2 - BISECTOR OF THE ANGLE FORMED BY TANGENTS TO THE NECK STRAP PASSES CLOSER TO THE ANTERIOR MOLAR.

the midsagital plane of the head. The resultant force (F) of Fl and Fr (the bisector of the angle formed by them) is not on the center line but an angle to the midsagital line so that it crosses the X axis on the side of the longer arm or the right side. The prime consideration then is that bisector of the angle formed by the tangents to the neck strap passes closer to the anterior molar.[2]

To quantitatively evaluate these lateral and distal forces is no easy task. Previously, crude spring gauges have been used to measure unilateral forces.[2,14] These gauges had been the only basis for the scarce data that has been collected.

Andreasen[8] designed a force board to establish and measure unilateral forces of eccentric headgear. The force board consisted of a plastic base on which two Correx gauges were mounted (0-1000 gram range). These gauges contained .045 inch tube fittings and were designed so that they would permit lateral adjustment to compensate for variations in the width and lateral movement in the facebow when it was mounted. A cervical strap holder was made to stimulate the neck. The force board was adjustable for variations in the anteroposterior dimensions of the neck. In order to reproduce the force, as distributed by the patient, the cervical strap holder was made to move freely about a center bearing and thus it equalized the forces on the outerbow arms. The use of a dental vibrator beneath the force board facilitated the removal of friction between the neck strap holder and the bearings.

Even though the information was most likely available the author neglected to mention the length of the outerbow arm, however the differential forces that were attained were reported. They were able to produce a 200 gram force on the shorter arm side and a concurrent force of 400 grams on the longer arm side. On the average, during the twelve week treatment period, the teeth in the 400 gram force group moved approximately two and one-half times as far as did teeth in the 200 gram force group. These factors were evaluated by the use of the spring loaded Correx gauges.

Drenker[5] also mentions that total or nearly total unilateral action can be created in the average case, when the longer arm is about two inches longer than the shorter arm. This statement is not backed by any data or explanation.

Haack and Weinstein[2], using Richard spring tension gauges showed that the longer side was about 1 and 1/2 inches (visual) longer and delivered a force about 3 times that of the shorter side, he proved this observation by means of a photograph showing the typodont, facebow in traction and spring guages hooked to the innerbow molar stops.[2]

Spring tension gauges have been used to evaluate force but it also is felt that they are not especially accurate. Tests indicate that the one-year old gauge tested fairly accurately up to 4 ounces, with the greatest deviation of error at 1.3 ounces. The two and one-half year old gauge was less accurate, with the greatest deviation of error at 1.8 ounces.[14]

Strain is a fundamental engineering phenomenon. It exists in all matter at all times, due either to external loads or the weight of the matter itself. Strains vary in magnitude from atomic demensions to distances easily discernable by the naked eye, depending upon the materials and loads involved. Scientists and engineers have worked for centuries in the attempt to measure strain accurately, but only the last decade has seen real advancement in the art of strain measurement. Average unit strain is the total deformation of the body in a given direction devided by the original length in that direction and, as such, has much greater significance than total strain. This is especially useful when one is evaluating the amount of strain that can be tolerated.

For economic reasons, material costs, transportation costs and for general convenience, it is desirable to keep the functional components of any machine or apparatus as small and light as possible. Prior to the advent of accurate strain determination, it was necessary to design complex mechanical parts principally on a cut and try basis. This involved making some calculations based on theory only approximately true, multiplying by a "safety factor" of 3 to 5, then building and testing the piece. In the event of failure, adding material in the critical section until a suitable component was evolved. Designing by this method was extremely wasteful in both time and material. A further stimulus was provided by the need in aircraft construction for minimum weight and maximum performance from every part. It was desirable to accurately determine local stresses so that the least amount of material could be distributed to the greatest advantage in the new designs or in the modifications of old designs.

Electrical strain gauges are instruments developed to detect any strain in the body to which they are attached. This is accomplished by a proportional change through some electrical characteristic of the gauge. The electrical variable commonly used is resistance. The resistant wire strain guage operates on the principle that any lengthening or shortening of the wire is accompanied by a change in the electrical resistance of the wire. This effect is presumably due to changes in mutual contact of the particles as the resistor is stretched or compressed. Thus when the strain gauge is adhered to the part being tested, the gauge will be strained the same amount and the electrical resistance will be altered. Unfortunately, it turns out that this highly sensitive to temperature change and it is markedly affected by changes in humidity. Another disadvantage is their tendency to age so that they may have to be recalibrated. Because these gauges are inexpensive to manufacture and have a high sensitivity to strain, they have obtained popularity by measuring strains in which the activation is evaluated far too rapid for temperature or aging to be of much importance.

The strain gauge must be connected to certain electrical instruments, such as a Wheatstone bridge, which will indicate small changes in resistance. Once this is done, the strain gauge will faithfully follow and report any strains occuring in the test surface in the direction of the gauge axis. The gauges have been widely used in the automotive industry, on locomotives, rails, and other railroad components; on structures such as bridges, buildings, and highways; and on all types of machinery like presses, machine tools, and cranes. These applications barely scratch the surface of possible uses for the wire strain gauges.[15]

Strain gauges have also been used in the physiologically related fields. With the introduction of electronic measuring devices and techniques, methods of measuring intraoral muscle activity became possible in 1948. Until this time, electrodynamagraphic quantification of normal functional intraoral pressure had been limited by the sophistication of the measuring device.

The resistant wire strain gauge was developed in 1938 by Simmons at the California Institute of Technology and Ruge at the Massachusetts Institute of Technology.[15]

Howell and Manley were the first to adapt an electronic strain gauge technique in their investigations of maximum biting forces. Their strain gauges had been devised for measuring oral forces which makes use of the principle of change in resistance of a coil. The deflection of this spring is proportional to the force applied and the deflection produces a change in resistance. The coil is of a tuned circuit which is doubled to a radio frequency oscillator. Force applied to the spring changes the resistance and tunes the coupled circuit away from the oscillator frequency. This permits the amplitude of the oscillation to increase and the magnitude of the grid current in the oscillator to be used as a measurement of biting force.[16]

Alderiso and Lahr[17] in 1953 used the resistant strain gauge with the Wheatstone bridge as a measuring device in their presentation of the dynamics on intraoral muscle activity.

According to Profitt, only since 1963 has the instrumentation itself reached a satisfactory stage of reliability and accuracy. The result of the development of high quality electronic amplification systems, which can handle the small signals from minature pressure transducers, will permit a more complete understanding of pressures in or outside the oral cavity.

The most recent technical step has been the development of a portable system which can be used for pressure recording outside the laboratory. Solid state devices made it possible to construct a special portable amplifier small enough to carry on field studies. This equipment was used in 1972 in central Australia to obtain labial and lingual pressure measurements on members of the Walbiri group.[18]

Strain gauges and their application have reached a high degree of sophistication. The normal thickness is .0009 $\pm$ .0002 inches. They can be elongated 3% with 95% accuracy. They can be operated at a temperature range of -325° F to + 400° F. The problem of aging has also been limited to what is known as a drift factor of less than 1 microstrain per minute.[19]

MATERIALS AND METHODS

Previous investigations and clinical evaluations of orthodontic forces were performed using either the Dontrix gauge or the Correx spring gauge. The Dontrix gauge measures to the nearest ounce, while the Correx gauge measures to the nearest 5 grams. Because of fatigue and force limitations these instruments sacrifice some accuracy.

The strain gauge PA-06-01 5EE-120 manufactured by Magnaflux Corporation was implemented for this study. These gauges were selected because of their consistant readings and reported accuracy (0.1 grams) (figure 3).

The gauges consist of a resistant wire folded back and forth on itself to take the form of a spring viewed from the side. When the gauge is compressed, as in the case of headgear wear, more electrical current is allowed to flow through the gauge. The amount of compression is correlated to electrical flow. With the use of known weights calibration can be completed by coordinating the given weight and the amount of electricity passing through the gauges (example 4,8, and 16 ounces)(figure 4).

Four gauges, with connecting wires soldered to the contact points, were glued on the facebow at the location of the left and right adjustment loops of the innerbow. They were placed to pick up forces transmitted to the molars in the distal direction (figure 5).

Cervical stimulation was an acrylic disk cut to the diameter of the average neck. The typodont and the neck simulation was mounted on

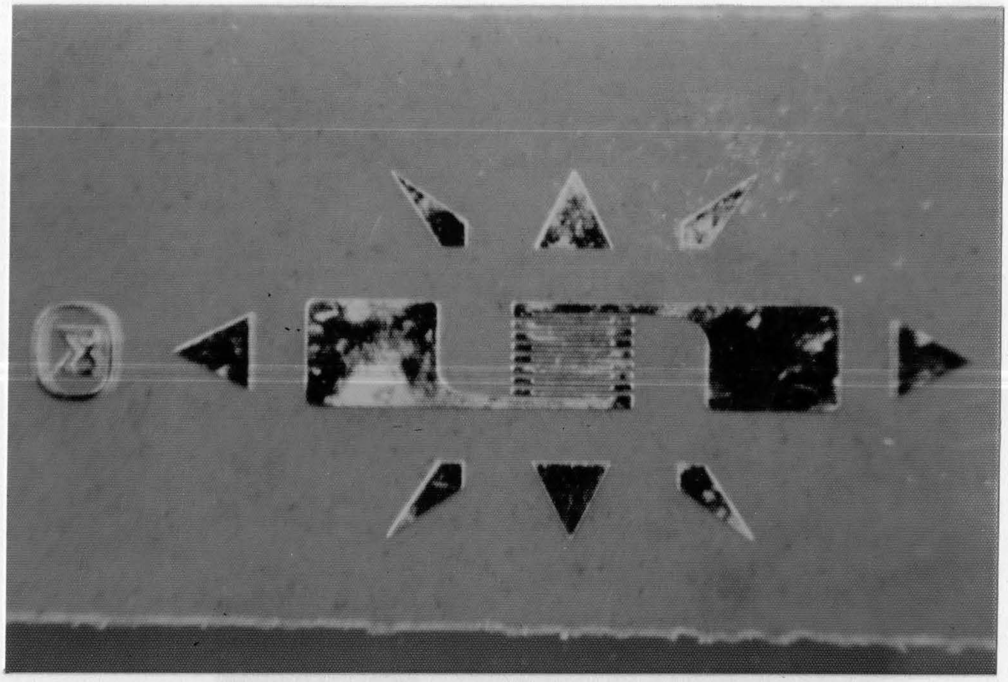


Figure 3 - STRAIN GAUGE PA-06-01 5EE-120

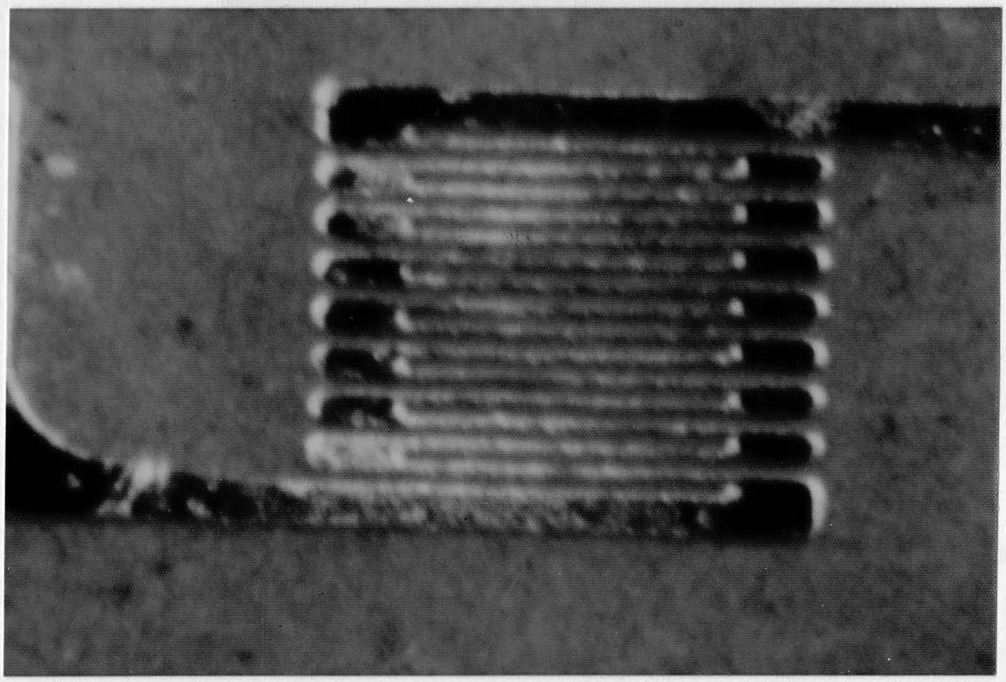


Figure 4 - CENTER SECTION OF STRAIN GAUGE

Figure 5 - STRAIN GAUGE MOUNTED ON FACEBOW UNDER PROTECTIVE COVERING.

an acrylic base that was bolted to a ½ inch aluminum shaft. The entire testing apparatus was supported by a heavy stone base. The typodont was positioned vertically so that forces of gravity could be implemented to simulate traction. A plumb line was used to maintain and verify the relationship between the pull of gravity and the testing apparatus (figures 6 and 7).

The equal balance position (B-1) was constructed to calibrate the strain gauges (figure 8). Two hooks (B and 1) were soldered to the outer facebow so that they would line up with the mesial border of the first molar bracket when the facebow was inserted in the buccal tubes.

The simulated neck strap (twenty pound braided fishing line) was fastened to the hooks at the equal balance position (B-1). From this position (B-1) the weight suspended from the simulated neck strap would be divided equally between the strain guages on the left and right sides (figure 9).

The calibration was accomplished by suspending 4, 8, and 16 ounce weights from the facebow at the equal balance position (B-1). The weights were suspended by a hook that was free to slide along the simulated neck strap to the centerline of the testing apparatus. This was done so that the pull of gravity simulated the traction used in the clinic. The same plumb line was used to verify the centerline relationship. Each weight was measured six times and a mean calculated. Measurements were taken from the left and right strain guages.

The remaining positions: #2, #3, #4, #5, and #6 were set at 10mm

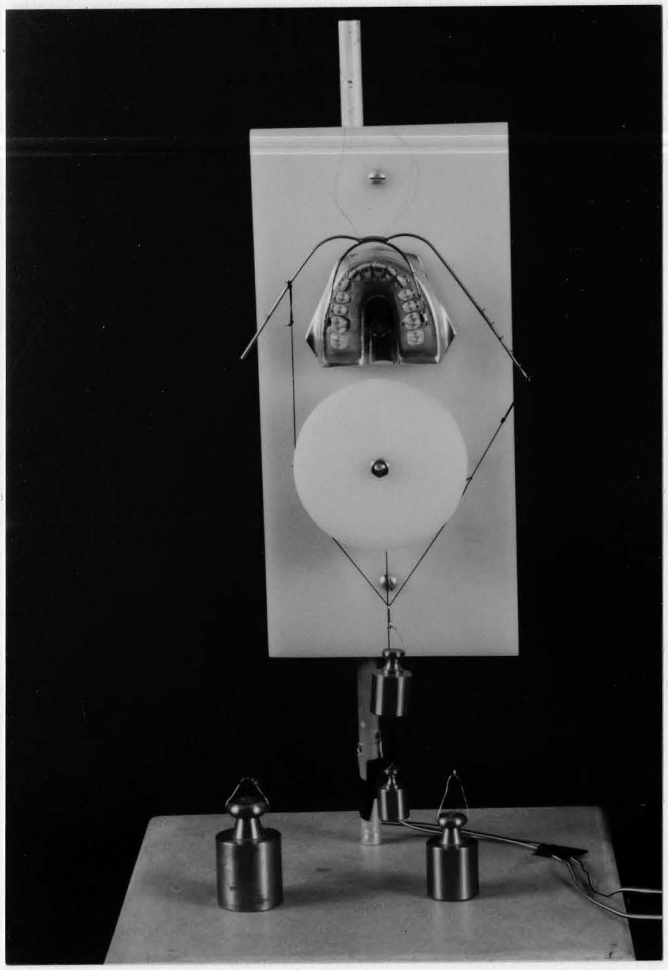


Figure 6 - FRONTAL VIEW OF TESTING APPARATUS

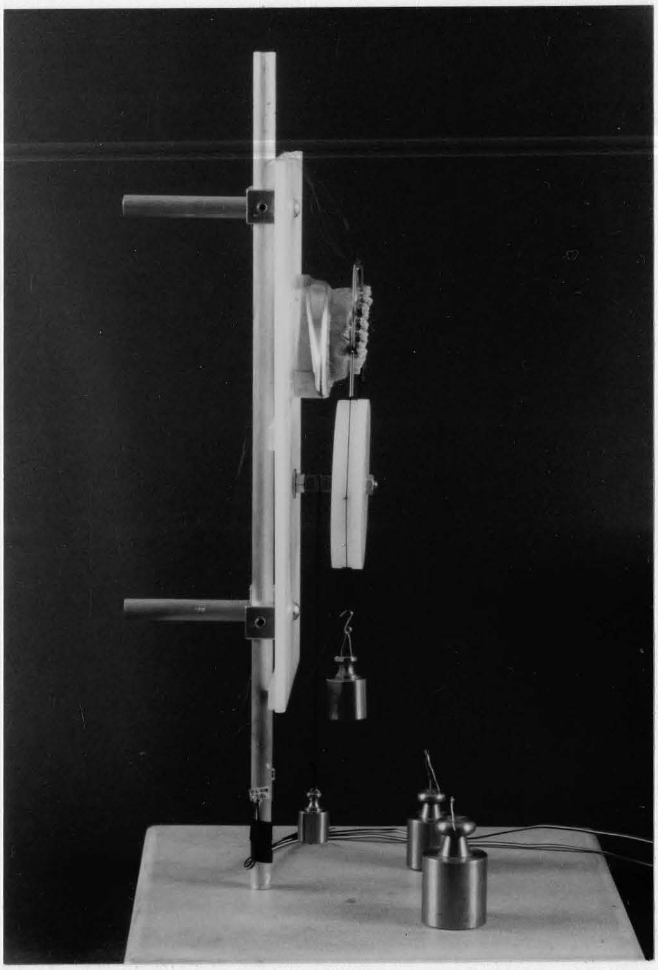


Figure 7 - LATERAL VIEW OF TESTING APPARATUS

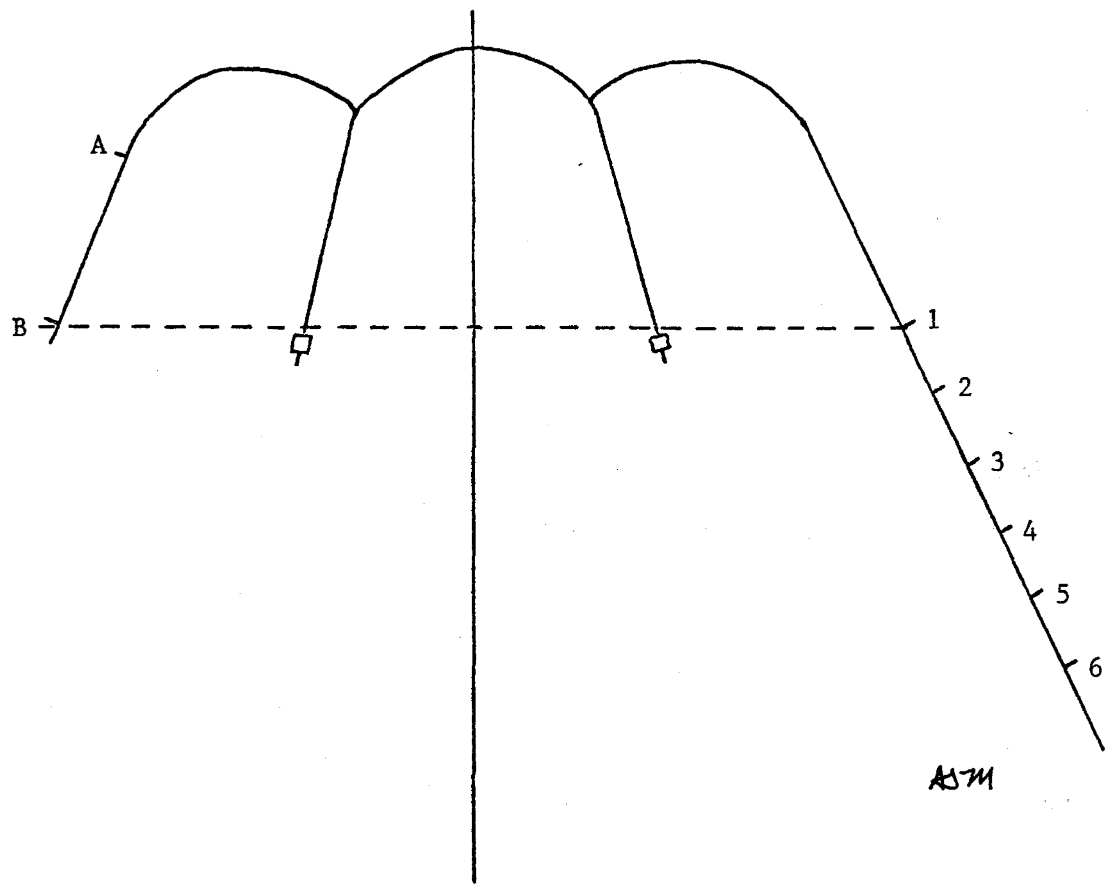


Figure 8 - POSITIONS OF THE SOLDERED STOPS PLACED ON THE FACEBOW.

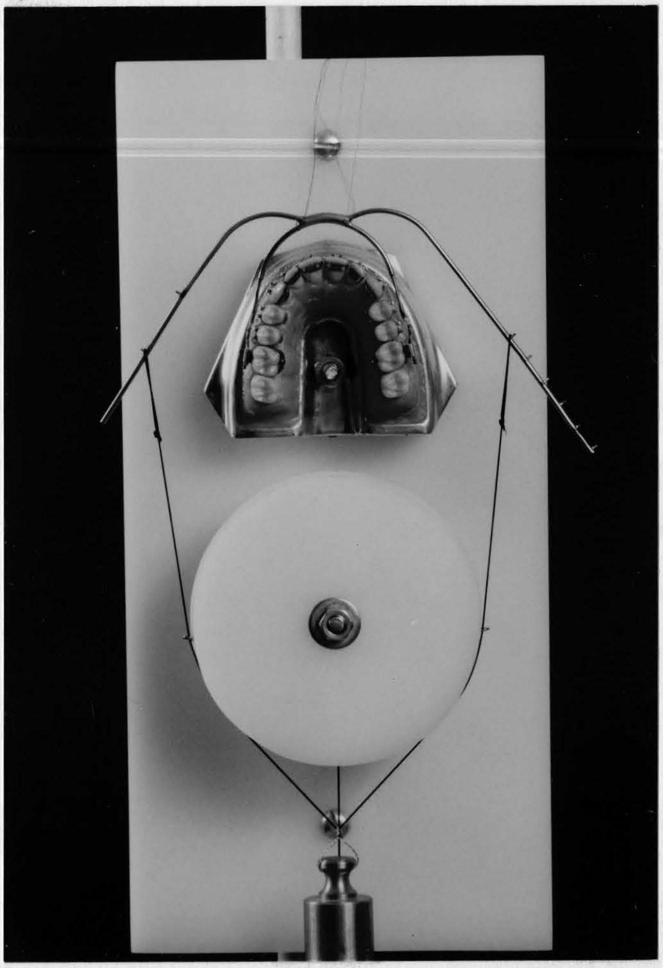


Figure 9 - EQUAL BALANCE POSITION

increments distal to the # 1 position along the longer outerbow side. The A position was soldered 25mm mesial to the B position on the shorter outerbow side (figure 10).

Sophisticated electrical equipment, the GA-100 Strain Indicator and the GB-100 Switch Balance Unit manufactured by Magnaflux Corp., was used to calibrate the gauges and record the data (figure 11).

The GA-100 Strain indicator needle would deflect as the weights were suspended. The microstrain units were recorded at the left and right terminals for each of the weights (4, 8, and 16 ounces). The A position was measured with each of the numbered positions on the longer outerbow arm (#1-#6). The same procedure was completed with the B position. Each combination was measured six times. A microstrain conversion factor (per side) was then calculated by use of this formula:

$$\frac{\text{MICROSTRAIN}}{\text{WEIGHT (OZ.)/2}} = \text{MICROSTRAIN/OUNCE}$$

This conversion factor was then used to normalize the data by this formula:

$$\frac{\text{GIVEN MICROSTRAIN}}{\text{CONVERSION FACTOR}} \times \text{OUNCES TO GIVEN SIDE} \times 28.35 = \text{GRAMS/SIDE}$$

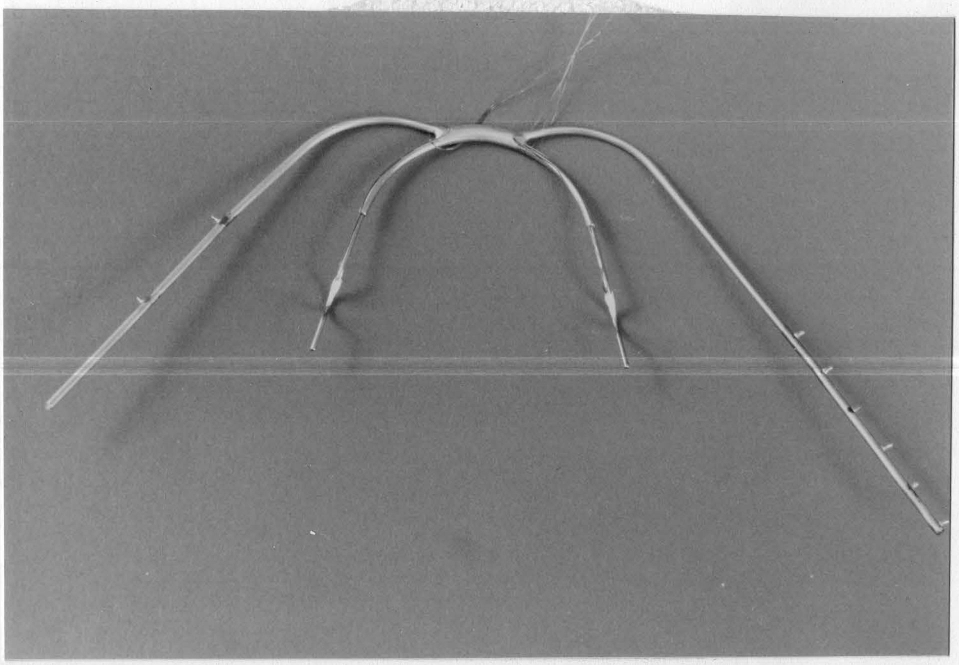


Figure 10 - FACEBOW WITH SOLDERED STOPS

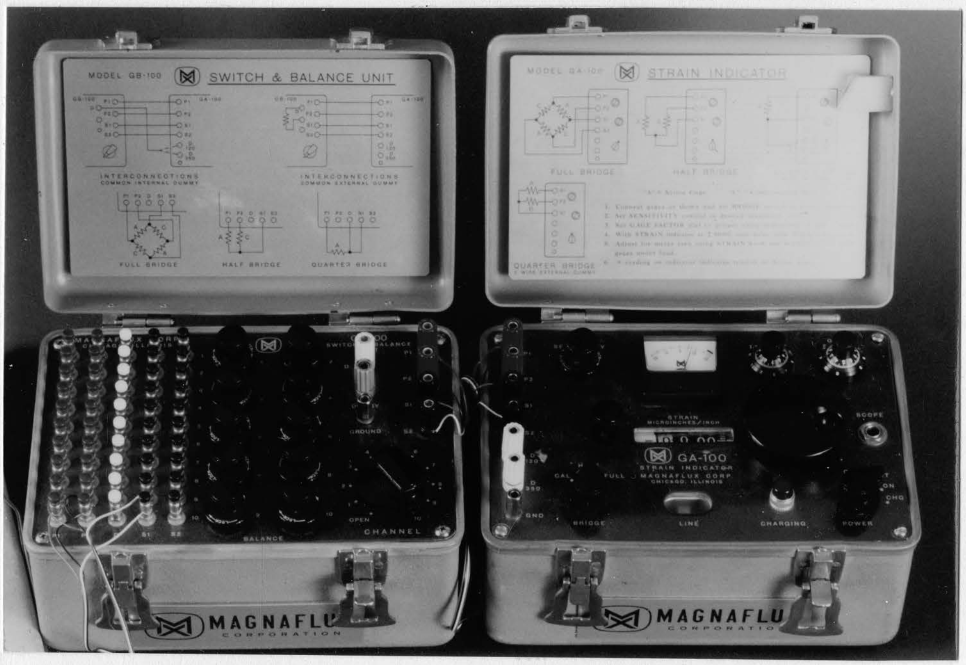


Figure 11 - (LEFT TO RIGHT) GB 100 SWITCH AND BALANCE UNIT AND THE GA STRAIN INDICATOR

CONVERSION FACTORS

Weight	Left	Right
4 oz.	1 oz. = 95 microstrain	1 oz. = 95 microstrain
8 oz.	1 oz. = 68.5 microstrain	1 oz. = 107.5 microstrain
16 oz.	1 oz. = 53.3 microstrain	1 oz. = 116.2 microstrain

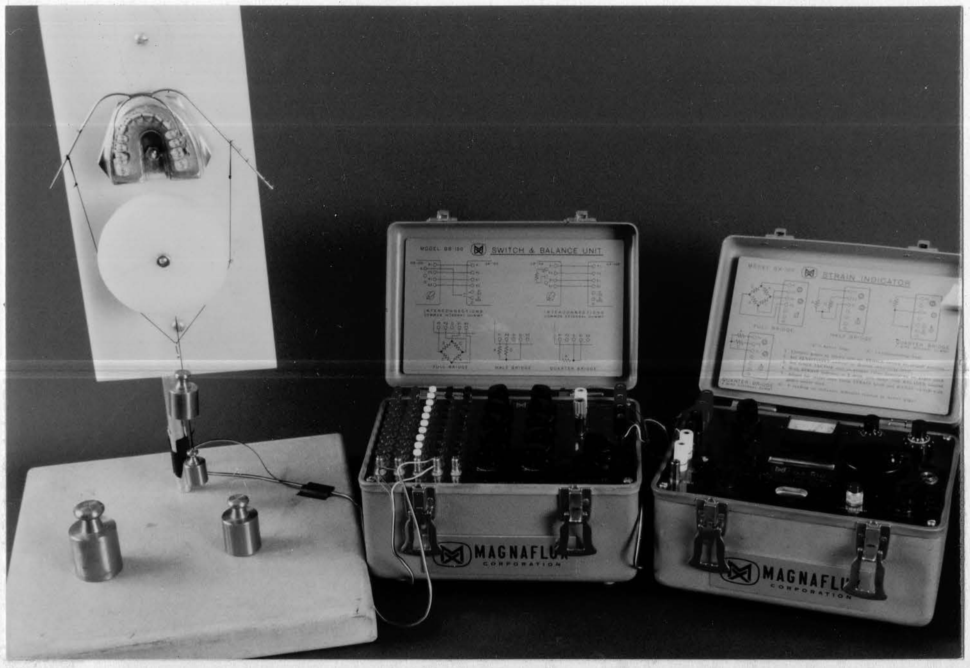


Figure 12 - THE ENTIRE TESTING APPARATUS

Figure 13 - RELATIVE SIZE OF STRAIN GAUGE

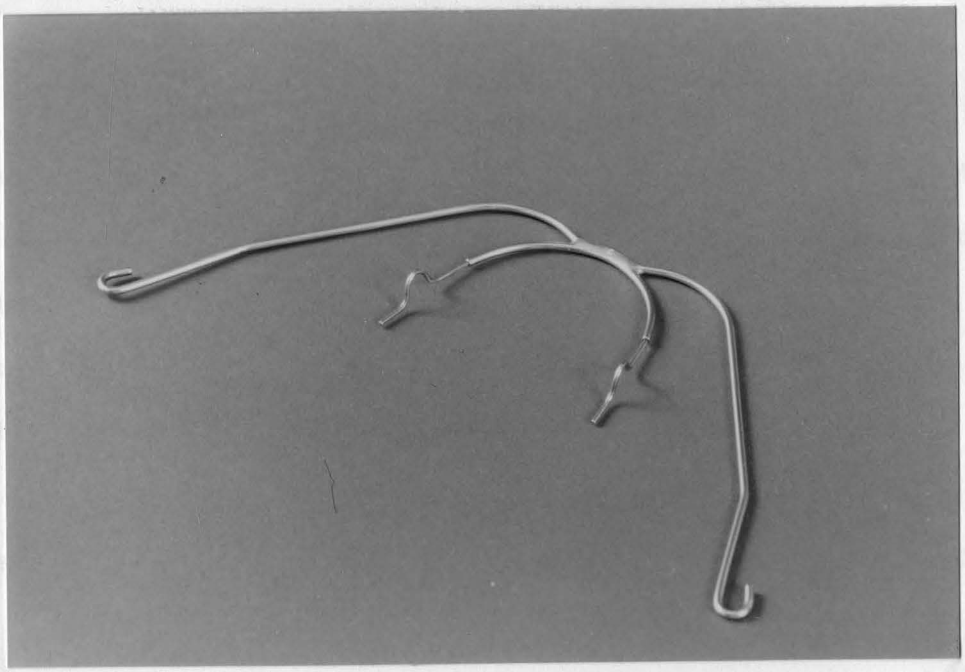


Figure 14 - NUMBER 4 ORMCO FACEBOW

RESULTS

The results of the strain gauge measurements are presented on Tables I, II, and III. Probability was calculated using the "two sample t test". The percent error was calculated by dividing the standard deviation by the mean.

4 Ounce Weight (Table I)

The readings from the 4 ounce weight were very consistent. The percent error was calculated to have a mean of 1.75% for the combinations with the A position and 1.93% with the combinations of the B position. The highest percent error was at the A-2 (left terminal) and B-2 (right terminal) positions (4.2%). The lowest percent error was at the A-5 (right terminal) and A-6 (left terminal) positions (.3%) (figure 8).

No statistical significance was seen until the #5 position, with the shorter arm combinations suspended from the B position (P=.05). When the weight was suspended from the B-6 position the statistical significance was greater (P=.01) (figure 8).

All data collected from the combinations of the A positions showed a significance (P=.01).

8 Ounces Weight (Table II)

The readings from the 8 ounce weight were very consistent. The percent error was calculated to have a mean of 2.88% for the combinations with the A position and 2.51% for the combinations with the B positions.

The highest percent error was 5.0% at the B-1 (left terminal) position. The lowest percent error was 1.5% at the B-5 (left terminal) position (figure 8).

All combinations taken with the B position, except the equal balance position (B-1), showed a statistical difference (P=.01). All combinations taken with the A position, except A-1 and A-3, showed a statistical significance (P=.01). Positions A-1 and A-3 showed no statistical significance at all. The B-1 position also showed no statistical significance.

16 Ounce Weight (Table III)

The readings from the 16 ounce weight were very consistent. The percent error was calculated to have a mean of 1.16% for the combinations with the A position and 1.72% with the combinations of the B position. The highest percent error was at the B-6 (right terminal) position (5.0%). The lowest percent error was at position A-2 (left terminal) (.6%).

All readings of all combinations were both A and B positions were statistically significant (P=.01). The only exception was the equal balance position (B-1) which showed no statistical significance at all (figure 8).

TABLE I - THE AMOUNT OF FORCE TRANSMITTED TO THE LEFT AND RIGHT STRAIN GAUGE TERMINALS WITH A 113.4 GRAM WEIGHT SUSPENDED FROM THE FACEBOW.

POSITION ON FACEBOW	LEFT TERMINAL MEAN FORCE IN GRAMS ± 1 S.D.*	PERCENT ERROR	RIGHT TERMINAL MEAN FORCE IN GRAMS ± 1 S.D.*	PERCENT ERROR	PROBABILITY***
A-1	47.75 ± .84	1.8	52.18 ± 1.46	2.7	.01
A-2	50.04 ± 2.11	4.2	56.39 ± .66	1.2	.01
A-3	47.95 ± .62	1.3	63.42 ± .76	1.2	.01
A-4	46.26 ± .90	1.9	67.83 ± .86	1.3	.01
A-5	46.05 ± 1.79	3.8	72.98 ± .26	0.3	.01
A-6	43.82 ± .74	1.6	72.76 ± .87	1.2	.01
B-1**	56.79 ± 1.26	2.2	56.59 ± .93	1.6	NS
B-2	58.19 ± .82	1.4	60.48 ± 2.55	4.2	NS
B-3	64.06 ± 1.63	2.5	64.68 ± 1.77	2.7	NS
B-4	66.15 ± 1.98	2.9	67.93 ± 1.46	2.1	NS
B-5	65.20 ± .59	0.9	71.19 ± 1.05	1.5	.05
B-6	59.58 ± .24	0.4	72.76 ± .34	0.4	.01

* STANDARD DEVIATION

** BASE REFERENCE POSITION

*** NULL HYPOTHESIS STATES THAT THERE IS NO DIFFERENCE BETWEEN THE FORCES DELIVERED TO THE LEFT AND RIGHT SIDES

TABLE II - THE AMOUNT OF FORCE TRANSMITTED TO THE LEFT AND RIGHT STRAIN GAUGES TERMINALS WITH A 226.8 GRAM WEIGHT SUSPENDED FROM THE FACEBOW.

POSITION ON FACEBOW	LEFT TERMINAL MEAN FORCE IN GRAMS ± 1 S.D.*	PERCENT ERROR	RIGHT TERMINAL MEAN FORCE IN GRAMS ± 1 S.D.*	PERCENT ERROR	PROBABILITY***
A-1	118.78 ± 2.39	2.0	90.02 ± 1.85	2.0	NS
A-2	131.61 ± 3.55	2.7	93.88 ± 4.53	4.8	.01
A-3	137.81 ± 3.01	2.2	98.59 ± 4.11	4.2	NS
A-4	141.40 ± 3.11	2.2	99.47 ± 4.19	4.2	.01
A-5	137.68 ± 2.75	2.0	103.47 ± 3.90	3.8	.01
A-6	129.39 ± 3.10	2.4	104.34 ± 2.04	1.9	.01
B-1**	113.39 ± 5.73	5.0	113.39 ± 1.82	1.6	NS
B-2	125.59 ± 3.46	2.7	108.74 ± 1.98	1.8	.01
B-3	143.06 ± 2.12	1.5	101.70 ± 2.86	2.8	.01
B-4	156.44 ± 2.92	1.8	110.15 ± 4.64	4.2	.01
B-5	159.89 ± 2.37	1.5	115.42 ± 2.86	2.5	.01
B-6	154.23 ± 4.08	2.6	105.93 ± 2.59	2.4	.01

* STANDARD DEVIATION ** BASE REFERENCE POSITION

*** NULL HYPOTHESIS STATES THAT THERE IS NO DIFFERENCE BETWEEN THE FORCES DELIVERED TO THE LEFT AND RIGHT SIDES

TABLE III - THE AMOUNT OF FORCE TRANSMITTED TO THE LEFT AND RIGHT STRAIN GAUGE TERMINALS WITH A 453.6 GRAM WEIGHT SUSPENDED FROM THE FACEBOW.

POSITION ON FACEBOW	LEFT TERMINAL MEAN FORCE IN GRAMS ± 1 S.D.*	PERCENT ERROR	RIGHT TERMINAL MEAN FORCE IN GRAMS ± 1 S.D.*	PERCENT ERROR	PROBABILITY***
A-1	222.69 ± 1.60	0.7	197.05 ± 1.89	0.9	.01
A-2	226.94 ± 1.45	0.6	191.60 ± 3.29	1.7	.01
A-3	247.33 ± 2.10	0.8	188.27 ± 1.78	0.9	.01
A-4	270.73 ± 2.67	0.9	179.73 ± 2.52	1.4	.01
A-5	281.16 ± 3.33	1.2	185.90 ± 1.87	1.0	.01
A-6	220.06 ± 3.25	1.5	207.13 ± 5.42	2.6	.01
B-1***	226.94 ± 2.09	0.9	226.98 ± 1.04	0.4	NS
B-2	243.43 ± 2.06	0.8	215.84 ± 4.25	1.9	.01
B-3	260.63 ± 2.69	1.0	220.31 ± 4.84	2.2	.01
B-4	270.20 ± 3.98	1.5	216.00 ± 5.56	2.6	.01
B-5	279.78 ± 2.23	0.8	219.67 ± 3.39	1.5	.01
B-6	257.79 ± 5.20	2.0	204.85 ± 10.26	5.0	.01

* STANDARD DEVIATION

** BASE REFERENCE POSITION

*** NULL HYPOTHESIS STATES THAT THERE IS NO DIFFERENCE BETWEEN THE FORCES DELIVERED TO THE LEFT AND RIGHT SIDES

TABLE IV - THE NUMBER OF MICROSTRAIN RECORDED AT THE LEFT AND RIGHT STRAIN GAUGE TERMINALS WITH A 113.4 GRAM WEIGHT SUSPENDED FROM THE FACEBOW.

POSITION ON FACEBOW	LEFT TERMINAL MEAN MICROSTRAIN ± 1 S.D.*	RIGHT TERMINAL MEAN MICROSTRAIN ± 1 S.D.*
A-1	160 ± 2.9	165.6 ± 4.6
A-2	167.6 ± 7.08	179 ± 2.09
A-3	160.6 ± 2.06	201.3 ± 2.42
A-4	155.0 ± 3.03	215 ± 2.73
A-5	154.3 ± 5.90	231 ± .8
A-6	146 ± 2.48	231 ± 2.75
B-1**	190 ± 4.50	179 ± 2.9
B-2	195 ± 2.75	192 ± 8.09
B-3	2.4 ± 5.46	205.3 ± 5.6
B-4	221.6 ± 6.6	215.6 ± 4.6
B-5	218.5 ± 1.97	226 ± 3.34
B-6	199.6 ± .81	231 ± 1.09

* STANDARD DEVIATION
** EQUAL BALANCE POSITION

TABLE V - THE NUMBER OF MICROSTRAIN RECORDED AT THE LEFT AND RIGHT STRAIN GAUGE TERMINALS WITH A 226.8 GRAM WEIGHT SUSPENDED FROM THE FACEBOW.

POSITION ON FACEBOW	LEFT TERMINAL MEAN MICROSTRAIN ± 1 S.D.*	RIGHT TERMINAL MEAN MICROSTRAIN ± 1 S.D.*
A-1	287 ± 5.76	341.3 ± 7.0
A-2	318 ± 8.57	356 ± 17.15
A-3	333 ± 7.34	373.8 ± 15.6
A-4	341.6 ± 7.5	377 ± 16.0
A-5	332.6 ± 6.65	392.3 ± 14.7
A-6	316 ± 7.5	395.6 ± 7.73
B-1**	274 ± 13.8	430 ± 6.92
B-2	303.3 ± 8.26	412.3 ± 7.52
B-3	345.66 ± 5.12	385.6 ± 10.8
B-4	378 ± 7.04	417.6 ± 17.6
B-5	386.3 ± 5.71	437.6 ± 10.8
B-6	372.6 ± 9.88	401.6 ± 9.8

* STANDARD DEVIATION
** EQUAL BALANCE POSITION

TABLE VI - THE NUMBER OF MICROSTRAIN RECORDED AT THE LEFT AND RIGHT STRAIN GAUGE TERMINALS WITH A 453.6 GRAM WEIGHT SUSPENDED FROM THE FACEBOW.

POSITION ON FACEBOW	LEFT TERMINAL MEAN MICROSTRAIN ± 1 S.D.*	RIGHT TERMINAL MEAN MICROSTRAIN ± 1 S.D.*
A-1	418 ± 3.01	807.6 ± 7.77
A-2	426.6 ± 2.75	785.3 ± 13.5
A-3	465 ± 3.94	771.6 ± 7.31
A-4	509 ± 5.01	736.6 ± 10.3
A-5	528.6 ± 6.28	762 ± 7.69
A-6	417.5 ± 6.12	849 ± 22.2
B-1**	426.6 ± 3.93	930.3 ± 4.27
B-2	457.7 ± 3.88	884.6 ± 17.3
B-3	490 ± 5.05	903 ± 19.9
B-4	508 ± 7.48	885.3 ± 22.8
B-5	526 ± 4.19	900.3 ± 13.8
B-6	484.7 ± 9.7	839.6 ± 42

* STANDARD DEVIATION
**EQUAL BALANCE POSITION

DISCUSSION

This study was undertaken to evaluate the distal forces transmitted to the molars when unilateral headgear therapy is used. An appliance was designed and fabricated for quantitatively evaluating these forces. The technique was to simulate the clinical use of unilateral headgear therapy as nearly as possible. Weights were used to simulate the traction used in the clinic.

Some clinicians believe that implementing a longer outerbow arm will produce greater distal movement to that given side. More specifically, is there really more force delivered to the longer outerbow side? If so, how much more force, and how much longer should one outerbow arm be than the other?

SUSPENSION OF 4 OUNCE WEIGHT

Upon analysis of the data collected from the suspension of the 4 ounce weight, it becomes readily evident that more force was delivered on the longer outerbow side. With the left shorter outerbow in the B position, (figure 8, Table I) the first statistical significance could be noted when the right longer outerbow was in the #5 position (P =.05). The longer arm was 20mm longer than the shorter arm. This is relatively close to what is cited in the literature. Haack[3] and Drenker[8] suggest that the longer outerbow arm be 1 to 2 inches longer than the shorter outerbow arm. The force produced was approximately 10 percent greater on the longer arm side. It is believed this difference would not produce noticeable results clinically.

However, when the 4 ounce weight was suspended from the left shorter outerbow A position (figure 8) a statistical significance (P = .01) was seen with all combinations of the right longer outerbow positions (#1-#6, figure 8, Table I). The smallest force difference was about 10 percent greater force on the longer outerbow side position A and #1. The largest difference was about 70 percent more force on the longer arm side position A and #6.

A facebow with a left shorter outerbow arm length similar to position A (approximately 25mm mesial to the first molar) and a right longer outerbow arm similar to position #6 (approximately 50mm distal to the first molar) would exert a more unilateral force to the right side. This force should be 70 percent greater on the longer outerbow side in proportion to the amount of cervical traction the operator uses. With such a large difference in lengths, (75mm) the lateral forces that are inevitably introduced must be considered. It is believed that in this application, the lateral forces introduced would have a more deleterious effect on the arch than the positive action of the unilateral force.

When this information is applied clinically, it would be prudent then to lengthen the side one wishes greater distal movement and shorten the other side. By only lengthening one side 50mm, the greatest difference achievable would be 22 percent (figure 8, Table I).

The possibility exists that the optimum combination could be produced by a shorter outerbow arm constructed 25mm mesial to the more occlussally correct molar and, a longer outerbow arm extending 30mm distal to the molar requiring greater distal movement. This combination was represented by A-4 (figure 15 and Table I). With this combination 46 percent more force would be delivered to the side greater distal movement is desired. This speculation is obviously conjectural and will remain so until the lateral forces are evaluated. Optimum force depends also, to a certain extent, on the patients biological variation.

It can be noted that all combinations of the A and B positions (figure 8) behaved as would be anticipated from the reports cited in the review of literature. The forces on the left shorter outerbow arm side were less and decreased as the right longer arm was lengthened. Consequently, the forces on the right longer arm side became greater than the left shorter arm. The forces on the right longer arm side continually increased as the longer arm was lengthened.

SUSPENSION OF 8 AND 16 OUNCE WEIGHTS

The suspension of the 8 and 16 ounce weights can be discussed as one entity. The forces recorded on the longer arm side were less than the shorter arm side. These recordings were very consistent with both weights and at all positions. The data collected for the 8 and 16 ounce weights contradicted the results of the 4 ounce weight and the literature reviewed. At this time, the testing apparatus and the collected data should be re-evaluated.

The strain gauge system provided a means of obtaining sophisti-

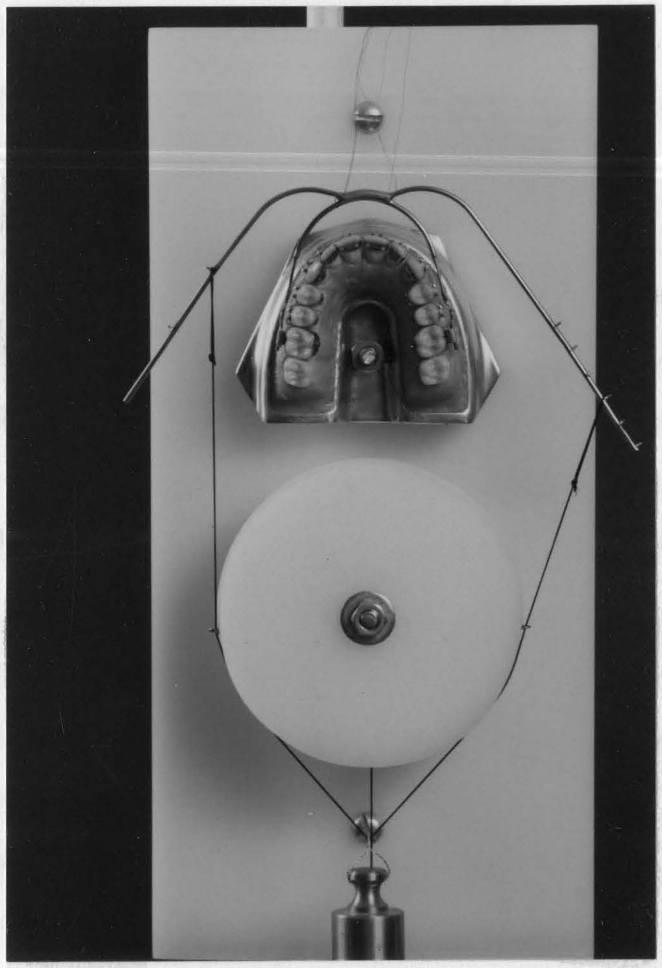


Figure 15 - POSITION A-4 PRODUCES 46% GREATER FORCE TO THE LONGER ARM SIDE.

cated consistant readings. Along with this sophistication, two major areas of difficulty were introduced:

1. The stabilization of the entire apparatus, specifically the facebow, at a position exactly perpendicular to the pull of gravity.
2. The flexibility of the facebow.

It is imperative that the axis of the strain gauge be kept in a constant relationship to the directional pull of gravity.

The original intention of this project was to measure the distal and lateral forces created on the molars when unilateral headgear therapy was used. Calibrating the strain gauges that were positioned to pick up the lateral forces proved to be much more difficult than anticipated. It was though that just securing the facebow in a clamp and suspending the weights perpendicular to the strain gauge axis would calibrate the gauges. This idea proved to be completely false. Attempting to evaluate the lateral forces on the molars, unfortunately, had to be discontinued.

Calibrating the distal forces was also difficult. The calibrating forces had to be in the exact line and relationship to the strain gauges as the weights would pull during the experimental set up. It was finally concluded to suspend the weights exactly in the midline of the two dimensional set up and assume that exactly half the weight was distributed to the gauges on each side when in the equal balance position (figure 9). The plumb line was used to orient the suspended weights through the midline of the testing apparatus.

Every effort was made to stabilize the apparatus and increase the reliability of the data collected. A large heavy stone base was used to stabilize and position the apparatus upright so that gravity could be used (figure 6 and 7). A plumb line was also used to assure that forces were in proper relationship to the pull of gravity (figure 6 and 7). An aluminum 1/2 inch shaft mounted by 1/4 inch stovebolts was used to support the acrylic base (figure 6 and 7). The aluminum shaft and acrylic base had a slight amount of flexibility in them. When the heavier weights were used, a slight amount of distortion in the testing apparatus was created. This distortion prevented the pull of gravity from exerting the same directional force as the original calibration, thus affecting the reliability of the data collected.

When analyzing the apparatus from a lateral view, it became obvious that it would be difficult to maintain the facebow so that gravity was exerting force down the central axis of the facebow (figure 7). The mere fact that the facebow was setting in the buccal headgear tubes allowed a teetering of the facebow. And of course, the miniscule swaying of the entire apparatus could not escape the sensitivity of the strain gauges. Any movement of any part of the apparatus that changed the axis of the strain gauge in its relationship to the pull of gravity, from which it was originally calibrated, would have an adverse effect on the reliability of the data.

The most difficult problem was the flexibility of the facebow, especially the longer arm side. Many attempts were made so that the only variables that were introduced into the testing apparatus were the suspended weights and the position of the simulated cervical strap.

The neck simulation was first made of several disks so that the simulated neck strap could rest at the same position and not slide off the simulated neck. This idea completely defeated the purpose of keeping the forces perpendicular to gravity and in one plane of space. The simulated neck was later limited to one disk with eyelets (figure 6 and 7). This was done so that the simulated neck strap could pass through the eyelets and maintain a more constant relationship to the axes of the strain gauges.

Facebow attempt # 1 was fabricated so that each position could be tested and retested without manually bending in the position like that done in the clinic. This precaution was taken so that less manual bending would be necessary and less chance that the electrical leads would be dislodged from the fragile solder joints on the strain gauges. A sliding acrylic sleeve was constructed with a set screw. The idea proved to be impractical because the set screw could not prevent the sleeve from rotating around the long axis of the outerbow arms.

Facebow attempt # 2 had the positions soldered in place to further reduce the amount of time spent manipulating the facebow. And of course, the soldered stops were also immobile.

Another problem encountered was the simulated neck strap used to suspend the different weights from the facebow. Dental floss was tried first because it was light and would not interfere as much with calibration. It was, however, too fragile and was continually breaking. Monofilament fishing line was tried next. It did not break but stretched when the heavier weights were used. Ligature wire (0.01 inch) was also tried but kinks were a major problem. The kinks made it difficult to slide the weight to the correct position as did the stretching monofilament line. The twenty pound braided fishing line seemed to work best.

FURTHER INTERPRETATION

With an appreciation for the difficulties encountered, further interpretation of the data is necessary. A review of the literature indicates that a greater distal force is exerted on the longer arm side.

When the 4, 8, and 16 ounce groups are compared it is readily apparent that the measurements agreed with the literature in the 4 ounce group but not in the 8 and 16 ounce group.

This deviation from what was anticipated may possibly be explained by an unstable calibration. When the weights were changed to the successive positions, the force exerted down the central axis of the strain gauge changed also but not necessarily due to the change in the weight positions. With the set up so designed it was virtually impossible to limit the experiment to one plane of space. The facebow would teeter slightly back and forth through the second plane of space. To repeatedly suspend the weights so that the force exerted was always in the same consistant relationship with the central axis of the strain gauges was extremely difficult if not impossible. This deviation was only accentuated with the heavier weights as can be noted in the results.

It was also interesting to note that the heavier 8 and 16 ounce weights showed a less frequent predictable change in the measurements recorded. The greatest number of unpredictable changes was observed on the longer arm in the 8 and 16 ounce group (Tables I, II, and III).

When the A and B positions on the shorter arm (figure 8) of the 8 and 16 ounce groups are compared to the longer arm, the degree of predictability is higher. This is to be expected because the shorter arm would be less flexible (Tables I, II, and III).

When the B position (of the equal balance position) is moved to the A position (figure 8 and 9), the amount of force increased. This was observed in the 8 ounce group on the left shorter arm side terminal. These measurements contradicated the literature reviewed and the data collected from the suspension of the 4 ounce weight. The 16 ounce group showed the same inconsistancy with the forces being both less and greater on the shorter arm side when compared to the basic reference position (Tables I, II, and III).

The recorded measurements also varied within the respective longer and shorter arm groups (Table I). On instances when the greater force was produced on the longer arm side, as in the 4 ounce group, there was a definite fluctuation between increases and decreases when the successive numbers on a give side were compared.

There are definitely forces introduced into the system. When these lateral forces exerted on the maxillary molars become great enough, it is conceivable that the distal forces would actually decrease. The testing apparatus design was intended to pick up forces expressed only in the distal direction. This idea may shed some light on the questionable results observed by some in the clinic. These untold lateral forces cannot be perpetually ignored. The lateral forces created on this flexible facebow could have been accentuated by the heavier 8 and 16 ounce weights (Tables I-VI).

ADAPTATION OF THE STRAIN GAUGE

The strain gauge is a valuable tool when evaluating strain. This data would have been much more significant if a more rigid facebow could have been used. This, however, would have been a deviation from the clinical simulation.

A more research oriented facebow would be one that would flex or bend in only one direction, or at least much easier in one direction than the other. Such would be the case with rectangular wire where one side of the cross section would be 2 or 3 times larger than the other side. This would help reduce the bending to one or two directions instead of the limitless possibilities exhibited by round wire. A more rigid facebow would also be better than the relatively flexable facebow material used.

Another consideration would be to take the strain gauges off the facebow completely and mount it on a rectangular post supporting the banded molars. A clinical facebow could be inserted in the buccal tubes. This design may lend itself to more accurate data and give some insight to evaluating the lateral forces. This rectangular post would bend either anteroposteriorly or mediolaterally. With this set up flexibility would become less of a problem.

Lateral forces should be evaluated. Some lateral forces are undeniably introduced into the system when unilateral headgear therapy is used. By leaving the clinical simulation for the time being and working with a purely mechanical representation these forces could be evaluated. Some insight could be provided as to why some clinicians use unilateral headgear therapy as a viable part of their practice, or why some believe that the clinical results are less than appreciable.

SUMMARY AND CONCLUSIONS

A technique was developed for measuring the distal forces when unilateral headgear therapy was used. An appliance was designed and fabricated for quantitatively evaluating these forces.

The technique was to simulate the clinical use of unilateral headgear therapy as nearly as possible. Weights were used to simulate the traction used in headgear therapy.

When the 4 ounce weight was used, the data collected followed in line with the reviewed literature. Ten percent greater force could be obtained by having the longer outerbow arm 50mm longer than the shorter outerbow arm. Seventy-five percent greater force could be produced by having the shorter arm shortened 25mm more. This does not take into account the lateral forces that are introduced. The evaluation of these lateral forces was the original intent of this thesis.

When the results of the 8 and 16 ounce group were compared with the 4 ounce weight and the reviewed literature inconsistancies were noted. The testing apparatus and the data collected was re-evaluated. The sensitivity of the gauges, the mobility of the stand, the flexibility of the facebow and the lateral forces introduced may afford some explanation as to why these inconsistancies occur among the different weights.

Many questions remain unanswered and it is anticipated that further research will explore this area. The most important question at hand is still the amount of lateral force that is applied to the teeth when unilateral headgear therapy is used. When the use and adaption of the strain gauges has been refined, when the testing apparatus has reached a higher plane of sophistication, the answer to this question and others will come forward.

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APPROVAL SHEET

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The final copies have been examined by the director of the thesis and the signature which appears below verifies that fact that any necessary changes have been incorporated and that the thesis is now given final approval by the committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

April 20, 1979 — James L. Sandrik

Date — Director's Signature